Amendments to the Specification:

Please replace the paragraph beginning at line 2, page 2 with the following:

Micro-structured fibres are known to exhibit dispersion properties that are unattainable in conventional optical fibres (see e.g. Ranka et al., Optics Letters, Vol. 25, No. 1, pp.25-27, 2000, Broderick et al. Optics Letters, Vol. 24, No. 20, pp. 1395-1397, 1999, Mogilevtsev et al. Optics Letters, Vol. 23, No. 21, pp. 1662-1664, 1998). These properties include shifting the zero dispersion wavelength below 1.3[[□]]μm. This has e.g. in the above-cited Ranka-reference been utilized for super-continuum generation of light over a very broad frequency range (covering visible to near-infrared wavelengths). The development of such white-light generators using micro-structured fibres was made possible through the design of micro-structured fibres with high anomalous waveguide dispersion at visible wavelength – and it has fuelled a large research interest into non-linear effects in micro-structured fibres (Fedotov et al. JETP Letters, Vol. 71, No. 7, pp. 281-284, 2000, Wadsworth et al. CLEO 2000, Paper PD1.5, 2000). The above-cited references all describe fibres with zero dispersion wavelength shifted below 1.3[[□]]μm. The fibres are characterized by a relatively high cladding air-filling fraction – air hole diameters, *d*, of more than 0.45 times the centre-to-centre distance between two nearest air holes, [[□]]Λ, and they all have a solid core. The size of the core is relatively small – about 1.5[[□]]μm in diameter. It is a disadvantage of the prior art fibres with zero-dispersion wavelength shifted below 1.3[[□]]μm that they are not strictly single-mode at visible wavelengths, but support a few (or more) guided modes. In the above-cited reference by Ranka et al., it is demonstrated that for relatively short fibre lengths, the fundamental mode of such fibres may be considered undisturbed by any higher order guided modes (i.e. there is a low coupling coefficient between the fundamental and the higher order modes). However, for guidance over longer fibre lengths (i.e. hundred of meters) it is a disadvantage of the prior art fibres with zero dispersion wavelength shifted below 1.3 [[□]]μm that they are not strictly single mode at visible wavelengths. It is a further disadvantage of the prior art fibres with zero dispersion wavelength below 1.3 [[□]]μm that they will be highly multimode at visible wavelengths if the core size is increased above 2 [[□]]μm. It would be an advantage if fibres with zero dispersion

wavelength shifted below 1.3 [[□]]µm could be realized so as to have a core that was comparable in size to that of standard transmission optical fibres (i.e. to have a core of around 5 micron in diameter).

Please replace the paragraph beginning at line 8, page 3 with the following:

Another important aspect of micro-structured fibres is that they may exhibit normal dispersion (or so-called negative dispersion) at near-infrared wavelengths. Fibres with large negative dispersion at 1.55 [[□]]µm are attractive for use as insertion-components in existing optical fibre communication links, as they may be used to compensate the positive dispersion around 1.55 [[□]]µm of already installed standard transmission fibres (i.e. fibres that are designed to operate in the second telecommunication window and have a zero dispersion wavelength at 1.3[[□]]µm).

Please replace the paragraph beginning at line 16, page 3 with the following:

Monro et al. have presented micro-structured fibres having dispersion values of about –30 ps/nm/km at 1.55 [[□]]µm (see Journal of Lightwave Technology, Vol. 17, No. 6, pp.1093-1102, 1999). The fibres presented by Monro et al. are characterized by a solid core surrounded by micro-structured cladding with a close-packed arrangement of identical air holes. The cladding holes have a size d/[[□]]Λ around 0.2. It is a disadvantage of the fibres presented by Monro et al. that the dispersion is not more negative than –30 ps/nm/km. DiGiovanni et al. (see US patent no. 5,802,236) have presented micro-structured fibres that provide significantly larger negative dispersion at near-infrared wavelengths. DiGiovanni et al. disclose micro-structured fibres that are characterized by a core and a micro-structured cladding. The cladding consists of inner and outer cladding features, thereby forming an inner and an outer cladding region. Both the inner and outer cladding of the fibres have an effective index that is lower than the core refractive index at all wavelengths. The features of the inner cladding region (preferably air holes) act to lower the effective refractive index compared to the effective refractive index of the outer cladding region. Hence, the fibres disclosed by DiGiovanni have a so-called "depressed" cladding design. The use of depressed cladding regions is well-known from the development of conventional dispersion compensating fibres (see e.g., M.Monerie, Propagation in doubly clad single-mode fibres, IEEE Journal of

Quantum Electronics, vol.QE-18, no.4, April 1982, pp.535-542). To those skilled in the art, it will be recognised that in order to increase the negative dispersion of the fibres disclosed by DiGiovanni et al., the size of the cladding features must be increased. Digiovanni et al. disclose fibres that have dispersion of up to –1700 ps/nm/km. It is a disadvantage of the fibres disclosed by DiGiovanni that the depressed cladding design does not allow to increase the inner cladding feature size so as to obtain negative dispersion of more than –2500 ps/nm/km. This latter limit of maximum obtainable negative dispersion was predicted by Birks et al. (see Photonics Technology Letters, Vol. 11, No. 6, pp. 674-676, 1999). Birks et al. studied the fundamental limits of negative dispersion that can be obtained in solid core micro-structured fibres made of pure silica and air. Birks et al. argue in the above-cited reference that by increasing the void size (air holes), the negative dispersion of micro-structured fibres is generally increased. Hence, an ideal micro-structured fibre (with respect to negative dispersion) consists - according to Birks et al. - merely of a thin silica rod (the fibre core) surrounded by air. Hence, Birks et al. made a prediction of the maximum obtainable negative dispersion based on the study of a solid silica rod surrounded completely by air (this case corresponds to the inner cladding features of the fibres disclosed by DiGiovanni et al. being so large that they overlap each-other). For such an ideal micro-structured fibre, Birks et al. found a dispersion of –2000 ps/nm/km. This result has been taken as the maximum obtainable negative dispersion that can be obtained using silica-based optical fibres. It is a disadvantage of the fibres disclosed by Birks et al. that a negative dispersion of more than –2500 ps/nm/km cannot be obtained. It is a further disadvantage of the fibres disclosed by Birks et al. and of DiGiovanni et al. that the fibre core must be very small (about 1[[□]]µm or less in diameter) in order to ensure single mode operation at near-infrared wavelengths while exhibiting large negative dispersion.

Please replace the paragraph beginning at line 9, page 5 with the following:

The present invention provides fibres that are substantially single mode at visible wavelengths while having zero dispersion shifted below 1.3 [[□]]µm. This application further discloses fibres that are strictly single mode, have a zero dispersion wavelength below 1.3 micron, and a core diameter of more than 2 [[□]]µm.

Please replace the paragraph beginning at line 8, line 6 with the following:

Also for non-linear fibres, dispersion plays an important role, and in order to realise improved non-linear fibres, it is vital to be able to control and manipulate the dispersion properties of such fibres accurately. The present invention also addresses fibres with special dispersion properties for a number of non-linear fibre applications in the near-infrared wavelength range. In particular, the present invention provides new micro-structured fibres with small cores and so-called flat, near-zero dispersion at near-infrared wavelengths (especially around 1.5[[□]]µm) for use as non-linear fibres.

Please replace the paragraph beginning at line 5, page 7 with the following:

It is, however, a disadvantage of the fibres with near-zero, flat dispersion disclosed by Ferrando et al. that the centre-to-centre,[[□]]Λ, spacing between two nearest air holes surrounding the core is equal to or larger than 2.3[[□]]µm – thereby limiting the smallest possible core diameter to around 4.6[[□]]µm. The exact, absolute value of the core diameter, naturally, depends on the definition of the core diameter. Unless otherwise stated, we will use the same core diameter definition as used in WO 99/00685, namely a core diameter defined as the distance from a centre of an innermost cladding feature to a centre of another innermost cladding feature, these two innermost cladding features being positioned substantially opposite each other with respect to the core center. For the fibre design used by Ferrando et al. this results in a core diametre equal to two times [[□]]Λ (hence Ferrando et al. disclose fibres with core diameters larger than [[Õ□□]]4.6µm). Alternatively, the core diameter may be defined from a circle connecting centers of the innermost cladding features – this may be relevant in the case of only a few innermost cladding features (such as 3 or 5). This later definition is in agreement with the core definition used in WO 99/00685. For core shapes with a strong deviation away from a circular shape, such as an elliptical or rectangular shape the core diameter should be defined most appropriate with respect to the mode field area, e.g. as the mid-value between lengths of the first and second main axes of the elliptical or rectangular shape.

Please replace the paragraph beginning at line 24, page 7 with the following:

It is an object of the present invention to provide optical fibers for non-linear applications, where the fibres are characterized by a core diameter smaller than 4[[□]]µm

as well as near-zero dispersion at near-infrared wavelength. In particular, it is an object to provide optical fibres with a core diameter smaller than 3.5[[□]]µm and dispersion that varies less than +/- 5ps/nm/km around zero over a wavelength range from at least 1.45[[□]]µm to 1.65[[□]]µm.

Please replace the paragraph beginning at line 7, page 8 with the following:

In this application we distinguish between "refractive index" and "effective refractive index". The refractive index is the conventional refractive index of a homogeneous material. In this application we consider mainly optical wavelengths in the visible to near-infrared regime (wavelengths from approximately 400nm to 2[[□]]µm). In this wavelength range most relevant materials for fibre production (e.g. silica) may be considered mainly wavelength independent, or at least not strongly wavelength dependent. However, for non-homogeneous materials, such as micro-structures, the effective refractive index is very dependent on the morphology of the material. Furthermore, the effective refractive index of a micro-structure is strongly wavelength dependent – much stronger than the refractive index of any of the materials composing the micro-structure. The procedure of determining the effective refractive index of a given micro-structure at a given wavelength is well-known to those skilled in the art (see e.g. Jouannopoulos et al, "Photonic Crystals", Princeton University Press, 1995 or Broeng et al, Optical Fiber Technology, Vol. 5, pp.305-330, 1999). The present invention takes advantage of specific micro-structure morphologies and their strong wavelength dependency in a novel manner and discloses fibres where the effective indices of the core and cladding regions are varying with respect to each-other in an untraditional way. Most importantly, there exists for certain fibres, disclosed in this application, specific wavelengths – so-called "shifting" wavelengths - for which the difference between the effective indices of core and cladding regions may change sign. The present inventors utilize this property to realize micro-structured fibres with strong dispersion around the shifting wavelengths.

Please replace the paragraph beginning at line 17, page 9 with the following:

A problem to be solved by the invention is to be able to guide light in single-mode micro-structured fibres with relatively large mode areas, where either the zero dispersion

wavelength is shorter than 1.3[[□]]µm or the fibres exhibit a large negative dispersion value around 1.55[[□]]µm. Another problem to be solved is to provide in single-mode micro-structured fibres with very small mode areas and a flat, near-zero dispersion at wavelengths around 1.55[[□]]µm.

Please replace the paragraph beginning at line 11, page 10 with the following:

The present inventors have realised that the prior art fibres with a solid core require small core diameters in order to obtain single-mode operation and large negative dispersion. For modern optical telecommunication systems based on standard transmission fibres with a zero-dispersion wavelength of 1.3 [[□]]µm, a very important fibre application today is dispersion compensation at wavelengths around at 1.55 [[□]]µm. However, for high capacity systems that are based on multi-wavelength channels (so-called dense wavelength multiplexed systems D-WDM), the prior art micro-structured fibres cannot be used for dispersion compensation due to their small core diameter. The small core diameter causes a (for this aspect) crucial increase in undesired non-linear effects - such as e.g. four-wave mixing.

Please replace the paragraph beginning at line 1, page 37 with the following:

N_i is larger than N_o at the operating wavelength, the core region is a substantially solid core with a core diameter around or below 4 µm and with an effective refractive index N_{co} being larger than N_i at the operating wavelength, the centre to centre spacing or pitch of the inner cladding features, Λ_i, is around or below 2 µm, the inner cladding features have a diameter or cross sectional dimension, d_i, fulfilling the requirement that d_i/Λ_i is equal to or below 0.7 and equal to or above 0.2, the centre to centre spacing or pitch of the outer cladding features, Λ_o, is around or below 2 µm, and the outer cladding features have a diameter or cross sectional dimension, d_o, fulfilling the requirement that d_o/Λ_o is equal to or above 0.4. The micro-structured fibre exhibits non-linear optical effects at wavelengths around 1.5[[□]]µm, such as in the wavelength range from 1.4[[□]]µm to [[□]]µm.

Please replace the paragraph beginning at line 12, page 48 with the following:

Fig. 28 shows an example of a fibre with a raised, inner cladding for non-linear applications at wavelengths around 1.5[[□]]μm.

Please replace the paragraph beginning at line 4, page 49 with the following:

Fig. 34 shows an example of a fibre with a raised, inner cladding for dispersion slope compensation at wavelengths around 1.5[[□]]μm.

Please replace the paragraph beginning at line 14, page 49 with the following:

Fig. 38 shows the mode field distribution of the fibre in Fig. 36 at a wavelength of 1.55[[□]]μm.

Please replace the paragraph beginning at line 21, page 49 with the following:

A typical micro-structured fibre known from the prior art is illustrated schematically in Fig. 1. The figure shows a cross-section of the fibre. The fibre consists of a background material (10) and it is invariant in the longitudinal direction (the direction perpendicular to the illustrated cross-section) and it has a cladding region characterized by an array of features (11) running along the fibre axis. In the prior art, the most commonly used background material is silica and the features are most commonly air holes. The holes are in this case arranged periodically (in a so-called close-packed or triangular arrangement), but the holes may also be non-periodically or randomly distributed (see e.g. Monro-reference). In the centre of the fibre (12) a single hole has been left out in order to form a high-index core region. In Fig. 2, the core region is schematically illustrated (20) along with the centre-to-centre distance between two nearest air holes, [[□]]Λ. In the case of micro-structured fibres with periodically arranged holes, these form in the cross-section a two-dimensionally periodic lattice with a lattice constant equal to [[□]]Λ.

Please replace the paragraph beginning at line 10, page 50 with the following:

Micro-structured fibres are commonly fabricated using a relatively simple procedure, where an array of silica rods and tubes are stacked by hand to form a preform, that may be drawn into fibre using a conventional tower setup. Various lattice structures may be realized using this technique by positioning rods and tubes during the stacking process in a close-packed arrangement. Such preforms are readily drawn to dimensions,

where centre-to-centre spacing between two nearest air holes may be less than 2.0[[□]]µm, while preserving the initial air hole lattice in the cross-section of the fibres. Fig. 3 shows an example of a final micro-structured fibre - with a regular air hole arrangement - that has been realized using a so-called stack-and-draw process. The fibre in Fig. 3 has air holes arranged in a triangular lattice, and a high-index core is formed by the omission of a single air hole. Light may be guided efficiently in the core region of micro-structured fibres, and an example of the fundamental mode that is guided in micro-structured fibre known from the prior art is illustrated in Fig. 4.

Please replace the paragraph beginning at line 24 page 51 with the following:

Fig. 5 shows the dispersion properties at near-infrared wavelengths of a series of typical

micro-structured fibres known from the prior art. The fibres have all a design as shown in Fig. 1, but the cladding air holes are varied from *d*/[[□]]<u>Λ</u>= 0.10 to 0.45. The simulation of the fibres is for a fixed [[□]]<u>Λ</u> value of 2.3 [[□]]<u>µ</u>m. The dispersion properties are simulated using a full-vectorial mode-solver as a function of wavelength. From the figure, it is first noted that for very small air hole sizes, e.g., when the influence of the air holes is strongly limited, the dispersion curve is very close to the material dispersion of pure silica (zero dispersion wavelength around 1.3 [[□]]<u>µ</u>m). As the diameter of the air holes is increased, the waveguide dispersion becomes increasingly strong. This shows that the waveguide dispersion may be positive at wavelengths below 1.3 [[□]]<u>µ</u>m, while the fibres simulated in Fig. 5 are all single-mode due to the relatively small size of the cladding holes (*d*/[[□]]<u>Λ</u> equal to or less than 0.45). These dispersion properties are well known for micro-structured fibres, but are unattainable for conventional optical fibres. Such dispersion properties may be utilized in applications such as white-light and soliton generators.

Please replace the paragraph beginning at line 15, page 51 with the following:

The air-filling fraction is a key parameter to increase in order to further increase the dispersion of micro-structured fibres. This may be desired in order to shift the zero-dispersion to even shorter wavelengths than presently possible, or to allow the use of shorter fibre length for obtaining a given dispersion effect. It is, however, well known

from the prior art that micro-structured fibres may become multi-mode for large cladding air-filling fractions – and that the largest possible cladding air hole size that can be employed in order for the prior art fibres to be strictly single-mode at all wavelengths is about *d*/[[□]]Λ=0.45 (see e.g. Birks et al, Optical Fiber Communication Conference, paper. FG4-1, 1999.).

Please replace the paragraph beginning at line 1, page 52 with the following:

The cut-off properties of prior art micro-structured fibres may be understood from Fig. 6, which shows the effective index of the guided modes of a micro-structured fibre with relatively large air holes in the cladding region. The cladding air holes are identical and they have a size *d*/[[□]]Λ=0.6, where *d* is the air hole diameter, and [[□]]Λ is the centre-to-centre spacing of two nearest air holes. The figure shows additionally the effective refractive indices of the core region and the cladding region. The core region is made of pure silica and it is, therefore, equal to 1.45 (which is a representative value for silica at visible to near-infrared wavelengths). The cladding region on the other hand contains air holes which act to lower the effective refractive index significantly below the index of the core region. The fibre supports at least two modes and the mode-field distribution of the second-order mode is illustrated in Fig. 7. The second-order mode has a mode cut-off wavelength of [[□]]Λ/1.5. Hence, to avoid the second-order mode at e.g. a wavelength of 632nm, the centre-to-centre hole spacing, [[□]]Λ, must be scaled to less than 1 [[□]]μm. For the specific fibre in Fig. 4, this gives a core diameter of less than 2 □m (the core diameter may be approximated by two times [[□]]Λ for the specific design).

Please replace the paragraph beginning at line 17, page 52 with the following:

In contrast to the fibre of the prior art, the present inventors have realised how to increase the features significantly above *d*/[[□]]Λ=0.45 (and thereby obtain the desired dispersion properties this gives access to) while keeping the fibres substantially single-mode at all wavelengths. This is obtained by applying into the core region elongated features with a size that is smaller than the size of the cladding features, while at the same time the core feature spacing is smaller than the cladding feature spacing. Hereby, the present inventors have realised that the cut-off wavelength of any higher order modes

may be pushed to very short wavelength – and for certain fibre dimension the second-order mode cut-off may be completely eliminated even for fibres with large features in the cladding. Figure 8 shows schematically a fibre according to the present invention, which has a background material (80) containing cladding features (81) of diameter, d_{cl}, and spacing, [[□]]$\underline{\Lambda}_{cl}$, and a core region (82) that contains (in this case) seven core features (83). A close-up of the core region is schematically illustrated in Fig. 9, where the core feature diameter, d_1, and the core feature centre-to-centre spacing, [[□]]$\underline{\Lambda}_1$, is illustrated. The fibre in Fig. 8 and 9 is characterized by $d_{cl}>d_1$ and [[□]]$\underline{\Lambda}_l$>[[□]]$\underline{\Lambda}_1$. While the Figures 8 and 9, show a fibre according to the invention with medium sized cladding features, fibres with even larger cladding features (d_{cl}/[[□]]$\underline{\Lambda}_l$ larger than 0.6) will be further advantageous when core features are provided. Fig. 10 shows a schematic example of a fibre according to the present invention with large cladding features (100) and smaller features (101) in the core region.

Please replace the paragraph beginning at line 12, page 53 with the following:

To illustrate the findings of the present inventors, the figures 11 to 13 documents how it is possible to eliminate the second-order mode (as well as any higher-order modes) by introducing features into the core region of a fibre with very large cladding features. In the specific example, the fibre consists of pure silica with features made of air. The cladding features have in the specific example a size of d/[[□]]$\underline{\Lambda}$=0.9. However, also for smaller cladding features it will be advantageous to introduce features into the core region. Fig. 11 illustrates the operation of fibre with a solid core (a fibre design that is known from the prior art). The figure shows the relation between propagation constant along the fibre axis, [[□]]$\underline{\beta}$, and free space wavenumber, k, for modes in the fibre. The propagation constant is normalized with respect to the cladding feature spacing, [[□]]$\underline{\Lambda}$. The fibre supports a multitude of guided modes, but only the two lowest order modes have been shown for reasons of clarity (the fundamental mode has the highest [[□]]$\underline{\beta}/k$ value for a given [[□]]$\underline{\beta}$ value). The semi-infinite, dark region (the region below the line corresponding to the effective refractive index of the cladding) illustrates the continuum of cladding modes existing in the fibre. In this region the fibre cannot guide light efficiently along its length in the fibre core. The right side of the figure illustrates schematically the fibre morphology, where full lines illustrate the air holes. By

introducing small features into the core region, the guided modes may be slightly pushed towards the dark region (the non-guiding region). This behaviour is illustrated in Fig. 12. If the core features are further increased in size, but still obeying the conditions that they should be smaller and more closely spaced than the cladding features, then the second-order mode may be completely eliminated. This behaviour is illustrated in Fig. 13. The advantageous of the type of fibre shown in Fig. 13 is that a strong dispersion can be obtained (a result of the large cladding features) while the fibre is strictly single mode. This can be used to shift the zero dispersion wavelength significantly below 1.3 [[□]]µm, while maintaining single mode operation. Furthermore, the type of fibre shown in Fig. 13 will have a larger core size than a fibre with similar sized cladding elements that has to obey the requirement of single mode operation. For the fibre shown in Fig. 13, the core size may be larger than 2 [[□]]µm in diameter and operate with large dispersion at visible wavelengths. In fact the core diameter may easily be designed to be in the interval from 2 to 10 [[□]]µm for the type of fibre illustrated in Fig. 13. Core sizes within this interval are of importance for a range of specific applications, where a high coupling coefficient between micro-structured fibres and conventional fibres are required. As a further mean to improve the coupling to conventional fibres, it is desired to shape the mode field using a high number of core features.

Please replace the paragraph beginning at line 4, page 57 with the following:

In a preferred embodiment, the cladding has features of size *d*/[[□]]Λ larger than 0.45 – and the core region contains more than one elongated feature (usually voids in the form of air holes). Preferably the number of core features is larger than 2 in order to utilize the core features to shape the guided mode of the fibre to a desired profile. Using just a single hole will either provide a single, centrally air hole – causing an undesired mode profile with a low coupling coefficient with respect to Gaussian mode profiles (that is the profile of conventional fibre) or cause an a-symmetric profile. Hence with the aid of two or more holes, the guided mode(s) may be shaped to more desired profiles, while at the same time serving to push the second-order mode cut-off to short wavelengths. Furthermore, it is preferred that the number of significantly higher than 2, such as higher than 5 or higher than 17 and that the spacing between core features becomes very small (much smaller than the wavelength of light guided through the fibre). By this, the light

will not be able to avoid the core features, and a large fraction of the light may, consequently, be guided within the features. In a further preferred embodiment, the features are voids containing air, a purified gas or vacuum, hence allowing a fibre to guide with low losses.

Please replace the paragraph beginning at line 20, page 57 with the following:

Apart from the potential of strongly shifting the zero-dispersion wavelength, Fig. 5 also shows a near-zero, broadband dispersion flattened behaviour of crystal fibres with d_{cl}/[[□]]Λ around 0.30. Due to the exhibition of positive waveguide dispersion at short wavelengths, the dispersion-flattened range is in fact extended to wavelengths below 1.3 [[□]]μm down to approximately 1.1 [[□]]μm. The attractive potential for micro-structured fibres of finding use as a standard transmission fibre in broadband optical communication seem, therefore, with respect to the dispersion properties, possible to fulfil. The large tailorability in the design of the crystal fibres, with respect to air holes sizes, shapes and arrangements provides a further fruitful mean of tuning of the dispersion curve to obtain specific properties. Micro-structuring of the core as disclosed in this application provides further flexibility for designing fibres with flat, near-zero dispersion over broad wavelength ranges.

Please replace the paragraph beginning at line 6, page 58 with the following:

Yet another aspect of micro-structured fibres is their ability to provide dispersion compensation at near-infrared wavelengths – and at 1.55 [[□]]μm in particular. The present inventors have realised how to provide a significantly higher degree of freedom for tailoring the negative dispersion of micro-structured fibres compared to both traditional fibres and previously known micro-structured fibres. The present inventors have realised a design-route for such micro-structured fibres, and the present invention discloses a number of specific design of micro-structured fibres with large negative dispersion.

Please replace the paragraph beginning at line 1, page 59 with the following:

Conventional optical fibres may be designed to exhibit normal dispersion. Such fibres are widely used on a commercial basis to provide dispersion compensation in

Received from < 6123329081 > at 8/14/03 5:40:50 PM [Eastern Daylight Time]

optical fibres systems that are upgraded from operation at wavelength around 1.3 [[❑]]μm to operation at wavelengths around 1.55 [[□]]μm. These dispersion-compensating fibres primarily allow us to significantly increase the transmission capacity over an existing fibre optical communication system. The dispersion compensating conventional optical fibres are commonly characterized by a so-called depressed cladding – an inner cladding region that has a lower refractive index than the core and an outer cladding region. Multiple depressed cladding designs are also well known from conventional optical fibres. Also micro-structured fibres have been designed for dispersion compensating purposes with a depressed, micro-structured, inner cladding region (see e.g. US patent no. 5,802,236). Both the conventional, dispersion compensating optical fibres, and the micro-structured fibres in the above-cited reference have an operation that is illustrated schematically in Fig. 15. The figure shows the effective indices (which in the case that one (or more) of the three illustrated fibre regions is homogeneous is identical to the conventional refractive index of that region(s)). The figure illustrates that the core at the operating wavelengths have the higher index, while the depressed, inner cladding region has the lowest. The outer cladding region has an index higher than the depressed cladding, but lower than the core at all wavelengths. The present inventors have, however, realised that it is not optimum to have the above-described relation between the fibre regions for all wavelengths. In contrast, the present inventors have realized that it is advantageous to have fibres where the relation between the effective refractive indices of the fibre regions is varying as illustrated in Fig. 16.

This application discloses fibres where the effective refractive index of the core may be larger than the effective indices of both an inner and outer cladding region at long wavelengths, the core index may be equal to the inner cladding index at a specific wavelength, named the shifting wavelength, but remain larger compared to the outer cladding at this wavelength, and finally, the core index may be lower than both the inner and outer cladding indices at short wavelengths. The effective index of the inner cladding region will at least at the operating wavelengths be higher than that of the outer cladding index, and we are, therefore, naming inner cladding regions, according to the invention as raised claddings. The present inventors have realized that a very strong dispersion can be

obtained around the shifting wavelength, and that this shifting wavelength can be designed to any desired absolute wavelength for a number of the fibres disclosed in this application. The above-described effect may e.g. be obtained by realizing a fibre as shown in Fig. 17. The fibre has a raised, inner cladding containing the features (170), and a solid core (171) that has a lower refractive index than the background material of the fibre (172). The outer cladding region contains larger features (173) than the features of the inner cladding region.

Please replace the paragraph beginning at line 8, page 70 with the following:

The present inventors have further realized that fibres according to the present invention may be used for non-linear applications at wavelength around 1.5[[□]]µm. Apart from providing fibres with a large negative dispersion, the use of an inner, raised cladding also allows to realize PCFs with flat, near-zero or zero dispersion at wavelengths around 1.5[[□]]µm for core sizes smaller than prior art fibres.

Please replace the paragraph beginning at line 14, page 70 with the following:

For non-linear applications, it is vital to realize fibres with small core sizes – typically with core diameters smaller than 3.5[[□]]µm as well as fibres with flat, near-zero dispersion around the desired operational wavelength(s). Ferrando et al. have presented PCFs with flat, near-zero dispersion for fibres with pitches from around 1.6[[□]]µm to 1.9[[□]]µm – resulting in core diameters of around 3.2[[□]]µm to 3.8[[□]]µm (see Ferrando et al. Electronics Letters, Vol. 35, No.4, Feb. 1999). The fibres presented by Ferrando et al. are, however, designed for near-zero dispersion at wavelengths around 1.0[[□]]µm. For use at wavelengths around 1.5[[□]]µm, the fibres presented by Ferrando et al. must have a larger pitch resulting in fibres having core diameters larger than 4.5[[□]]µm.

Please replace the paragraph beginning at line 24, page 70 with the following:

Monro et al. (Journal of Lightwave Technology, Vol. 17, No. 6, June 1999) and Ferrando et al. (See Ferrando et al., Optics Letters, Vol. 25, No. 11, June, 2000) have specifically investigated fibres with flat, near-zero dispersion around 1.55[[□]]µm. Both Monro et al. and Ferrando et al. find flat, near-zero dispersion properties for PCFs with a

pitch of 2.3[[□]]μm or larger – resulting in fibre diameters of 4.6[[□]]μm or larger. It is a disadvantage of the fibres presented by Monro er al. and by Ferrando et al. that they do not have flat, near-zero dispersion at wavelengths around 1.5[[□]]μm for pitches smaller than 2.3[[□]]μm. As shall be demonstrated by way of example, the present inventors have realized that the use of a raised, inner cladding may provide PCFs with near-zero, flat dispersion at wavelengths around 1.5[[□]]μm for smaller core sizes than known in the prior art (for pitches smaller than 1.8[[□]]μm – corresponding to core diameters of 3.6[[□]]μm or smaller). PCFs according to the present invention are characterized by a lower threshold for non-linear effects compared to prior art fibres, and will, therefore, be advantageous.

Please replace the paragraph beginning at line 13, page 71 with the following:

To analyse the dispersion properties of fibres with a design as illustrated in Fig. 28 and Fig. 29, a background refractive cladding index of 1.45 (for both cladding regions) and a highest refractive index in the core of 1.47 is chosen. A refractive index value of 1.45 is representative for silica at near-infrared wavelengths and a index increase of 0.02 is feasible with conventional doping techniques. The inner cladding holes (281) have a diameter of 0.3[[□]]Λ and the outer cladding holes (282) have a diameter of 0.6[[□]]Λ. Fig. 30 illustrates the dispersion properties of such fibres for [[□]]Λ ranging from 1.0[[□]]μm to 1.5[[□]]μm. As seen from the figure, a fibre with a small pitch of around 1.4[[□]]μm has a near-zero dispersion with a near-zero slope over a (very) broad wavelength range covering wavelengths of at least 1.2[[□]]μm to 1.8[[□]]μm. A close up of the dispersion properties of a similar fibre, but with outer cladding holes of diameter 0.5[[□]]Λ is illustrated in Fig. 31. Also for this fibre a flat, near-zero dispersion is found for small pitches – in this case a pitch of 1.5[[□]]μm. The two above-studied fibres with pitches of 1.4[[□]]μm and 1.5[[□]]μm have core diameters of 2.8[[□]]μm to 3.0[[□]]μm. This is significantly smaller than for prior art fibres with flat, near zero dispersion at wavelengths around 1.5[[□]]μm, and the fibres disclosed in this patent application are, therefore, advantageous for non-linear fibre applications at near-infrared wavelengths.

Please replace the paragraph beginning at line 5, page 72 with the following:

Fig. 32 illustrates the field distribution of a guided mode at a wavelength of 1.5[[□]]$\underline{\mu m}$. As can be seen from the figure, the mode experiences a strong confinement to the core region.

Please replace the paragraph beginning at line 13, page 72 with the following:

Although the previous dispersion analysis was done for fibres with a higher refractive index in the central core region compared to the cladding indices, the use of a raised, inner cladding also allows to realize fibres with the desired dispersion properties in the case of a core region having a lower refractive index than the background refractive index of one or both the cladding regions. Fig. 33 illustrates the dispersion properties of a fibre having a design as illustrated in Fig. 28, but the cladding background refractive indices being 0.02 higher than the core background refractive index (the refractive index values of 1.47 and 1.45 were used for the background material of the cladding and core, respectively). As seen from the figure, also this design provides a flat, near-zero dispersion around 1.5[[□]]$\underline{\mu m}$ for small pitches ([[□]]$\underline{\Lambda}$ of around 1.2[[□]]$\underline{\mu m}$). This specific fibre has d_i=0.4[[□]]$\underline{\Lambda}$ and d_o=0.7[[□]]$\underline{\Lambda}$.

Please replace the paragraph beginning at line 24, page 72 with the following:

The present inventors have realized yet another range of designs for non-linear fibres with flat, near-zero dispersion at wavelengths around 1.5[[□]]$\underline{\mu m}$. An example of the design is illustrated in Fig. 36. The fibres has a low number of innermost cladding features (innermost with respect to the fibre core). In the example in Fig. 36, the fibre has four inner cladding features (362) that surround the core (360). The fibre also comprises outer cladding features (361) arranged in a concentric, annular manner surrounding the core. The outer features do not necessarily need to be position in a concentric manner, but may also be close-packed. Due to the low number of inner cladding features (being lower than six which is the most generally studied case in the prior art), the fibre in Fig. 36 will also have a higher refractive index of the inner cladding compared to the micro-structured region(s) surrounding the inner cladding. The low number of innermost cladding features provides a larger spacing between the innermost cladding features compared to the outer cladding features – and since all cladding features are similar in size, the filling fraction

in the inner part of the cladding will be lower than in the outer part. Naturally, in the case of low-index features, this provides a larger effective refractive index of the inner cladding compared to the outer cladding. The present inventors have studied a number of fibres having less than six innermost cladding features (such as 5, 4, 3, and 2 innermost cladding features). As an example of the dispersion properties that may be obtained for such fibres, Fig. 37 shows the dispersion properties of an exemplary fibre with a design as shown in Fig. 36, where the cladding features are air and the cladding background material is pure silica (with a refractive index of 1.45), and the core is solid comprising Ge-doped silica (with a refractive index of 1.47). The cladding features are all similar sized with a diameter of 0.5[[□]]μm. The cladding features are arranged in concentric annular regions (rings), and the number of features in each ring (counting from the core) is 4, 22, 34, and 46. The smallest spacing between a centre of a cladding features in one ring to a centre of a cladding feature in another ring being 1.27[[□]]μm. The core diameter of the fibre is around 1.8[[□]]μm (defined as the distance from a centre of one innermost cladding features to a centre of a second innermost cladding feature – these two innermost cladding features being positioned opposite each other with respect to a centre of the core). As seen from Fig. 37, the fibre exhibits near-zero dispersion over an extremely broad wavelength range – the dispersion varying less than between +0.4ps/nm/km and

-4ps/nm/km over more than 600nm (for wavelengths between at least 1.2[[□]]μm to 1.8[[□]]μm). Fig. 37 shows further a close-up of the dispersion from 1.4[[□]]μm to 1.7[[□]]μm – the dispersion varying less than from +0.4ps/nm/km to –0.4ps/nm/km in the important wavelength range from 1.4[[□]]μm to 1.6[[□]]μm. At a wavelength of 1.5[[□]]μm, the mode field distribution (380) of the guided mode of the fibre is illustrated in Fig. 38. The field has a mode field diameter of only 1.7[[□]]μm. This small mode field diameter and the near-zero, flat dispersion of the fibre at wavelengths around 1.5[[□]]μm, make the fibre highly attractive for non-linear fibre applications. It is important to understand, that the low number of innermost cladding features acts to provide an effectively higher refractive index of the inner part of the cladding compared to the outer parts of the cladding. This is obtained by having substantially similarly sized

inner and outer cladding features, where the spacing between inner cladding features is larger than the spacing between outer cladding features (in the same annular region).

Please replace the paragraph beginning at line 11, page 75 with the following:

Potential applications of PCFs according to the present invention are: pulse compression (using self phase modulation), soliton generation and propagation, supercontinuum generation around 1.5[[□]]μm or other wavelengths, wavelength conversion (using four wave mixing), fibres for narrow bandwidth spectral shaping (using stimulated Brillouin scattering), fibres for wide bandwidth spectral shaping (gain equalising/flattening using cross phase modulation), Raman amplification, etc.

Please replace the paragraph beginning at line 18, page 75 with the following:

Another example of a fibre according to the present invention is illustrated in Fig. 34. A part of the core region (341) has a higher refractive index than the cladding background refractive index. The inner cladding region contains a honeycomb-like micro-structure (342) and the outer cladding region contains a micro-structure resembling the inner cladding structure, but with the addition of small features (343) in the centres of the honeycomb-cells. These small features provide a lower refractive index of the outer cladding region compared to the inner cladding region. The field distribution of the fundamental mode is illustrated in Fig. 35. The fibre has a large negative dispersion slope at wavelengths around for 1.5[[□]]μm – making it useful for dispersion slope compensating applications. The centre-to-centre air holes spacing is 1mm – resulting in a fibre with giving a mode field diameter of around 8[[□]]μm.